# The Application of Vacuum Tube Amplifiers to Submarine Telegraph Cables

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SYNOPSIS: Vacuum tube amplifiers have been developed for use in submarine telegraph reception and at present are in successful operation on four high speed permalloy cables. There is no limit to the speed at which vacuum tube amplifiers may be operated and in the present stage of development, the rate at which messages may be passed over loaded cables of the length used in the Atlantic Ocean is determined by the cable itself and the mechanical transmitting and receiving apparatus. In regard to maintenance, vacuum tube amplifiers have a great advantage in that they do not require any delicate mechanical adjustments.

THE laying of the new permalloy loaded cable between New York and Fayal (Azores) in September 1924 marked the most radical change in construction and operation of submarine cables that has taken place in many years. During 1926 three additional cables of this type were laid, the four sections being arranged to provide a line of communication between New York and England and another between New York and Germany. The traffic handling capacity of these cables when ultimately developed to its maximum by suitable terminal apparatus, will be nearly equal to that of all the other cables between North America and Europe combined.

The construction of these cables and the principles underlying their operation have already been described by O. E. Buckley[1] before the American Institute of Electrical Engineers in June 1925. The speed of operation of loaded cables of this type is many times that of the older non-loaded cables, and new apparatus has had to be developed to realize the full advantage offered by permalloy loading. One of the most important of these new developments has been the signal shaping vacuum tube amplifier, which is now in use on the four North Atlantic loaded cables.

The purpose of this paper is to point out the requirements which must be met by cable amplifiers, particularly those used on high speed loaded cables, and to describe how these requirements have been fulfilled in the present signal-shaping amplifier of the Western Electric Co. It will not be necessary to consider in any detail the general principles of operation of telegraph cables as these have been discussed with reference to non-loaded cables by Mr. J. W. Milnor[2] and are

[1] *Bell System Technical Journal*, Vol. 4, July 1925; *Journal of the American Institute of Electrical Engineers*, Vol. XLIV, No. 8, August 1925.
[2] "Submarine Cable Telegraphy," *Journal of the American Institute of Electrical Engineers*, Vol. 41, February 1922.

considered with particular reference to loaded cables in the paper by Mr. A. A. Clokey published in this issue of the *Bell System Technical Journal.*

## THE NECESSITY OF CABLE SIGNAL AMPLIFIERS AND THEIR REQUIREMENTS

Telegraph signals passing over a long submarine cable are distorted so severely that only a small fraction of the ultimate speed would be possible if extraordinary means were not taken to compensate for this distortion. It may be found that a certain cable attenuates very low frequencies to only one half of their original voltage while the higher frequencies may be received at less than one ten-thousandth of their initial strength. The transmission of an ideally perfect signal requires that its components of all frequencies be received at amplitudes proportional to those transmitted, consequently the reshaping of a signal received from a cable involves equalizing the strength of all its component frequencies by reducing the amplitude of the lower frequencies and amplifying the higher frequencies.

As the voltage which may be impressed upon a cable is limited by considerations of the safety of its insulation, the sensitivity of the receiver to currents of the highest frequency necessary in a properly defined signal is one of the limitations of the speed at which a cable may be operated. Unfortunately this is not the only limitation or it would be possible to increase the speed indefinitely by simply increasing the sensitivity of the receiver. All cables are exposed to extraneous interfering currents, some natural in origin and some the result of human activities, and while a great deal may be accomplished by proper design of the cable and the associated apparatus the speed is ultimately limited by interference. A large proportion of this interference is similar in nature to "static" and the bane of radio communication is also, but to a lesser degree, the bane of cable communication.

Experience has shown that continuous communication of the high standard of accuracy required in the transmission of code and cypher messages cannot be maintained unless the voltage received at the nominal signaling [3] frequency is between two and five millivolts. A receiver must therefore be capable of responding to voltages of this order at the signaling frequency in order to utilize the cable efficiently. On an average cable the power available at this voltage is of the order of $2 \times 10^{-8}$ watts and there is at present no signal recording device

[3] This is defined in the case of the Morse cable code as the fundamental frequency in a series of alternate dots and dashes.

known to the art which will operate on so small a power except at uneconomically low speeds. For this reason it is necessary to insert between cable and recorder an instrument which will amplify the received signal.

A cable signal-shaping amplifier must fulfill many severe requirements. With its associated apparatus it must be capable of correcting the attenuation of the cable by equalizing the strength of all important component frequencies of the signal and it must also be capable of controlling in its output circuits a power many times as large as it receives.[4] It must be as insensitive as possible to interfering currents not included in the band of frequencies necessary to the signal and it is very desirable that overloading, which may be caused occasionally by these currents, should not permanently influence its adjustment or destroy any of its elements. The strength of its output current should be readily adjustable. It should be mechanically rugged, as otherwise its maintenance will require too large a proportion of the time of the staff at the cable station, and delays to traffic will be caused. Finally it should be protected as well as possible against local electrical fields and mechanical vibration and its operation should not be affected by conditions of extreme humidity.

## Comparison of Mechanical Amplifiers and Vacuum Tube Amplifiers

In recent years several satisfactory mechanical amplifiers (called magnifiers in cable parlance) have been invented and their use has led to radical improvements in the speed of transmission over non-loaded cables. Most of these magnifiers utilize a sensitive moving-coil galvanometer, which moves some device a small distance in order to control a much greater power than that which caused the original motion of the coil. We may consider as typical of these the selenium magnifier which causes a beam of light to move over one or the other of two groups of selenium cells and thus varies their resistance, the Heurtley hot wire magnifier which changes the resistance of two pairs of almost microscopic heated wires by causing them to move relatively to each other, and the electrolytic magnifier which changes the resistances of a group of immersed electrodes. With all of these devices the controlled power is obtained from a local battery, but it is so small that it can do little more than operate a sensitive siphon recorder or a delicate moving coil relay. The latter may of course control a larger power which may in turn cause the operation of a comparatively rugged electromagnetic relay and thus indirectly a considerable power

[4] In practice the power amplification factor of the various types of amplifiers may range between five thousand and one hundred million.

may be controlled. With any of these magnifiers the suspended coil forms a mechanical oscillating system which is of great assistance in correcting the distortion of the cable, and allows signals to be shaped properly with the aid of a simple network of inductance, capacity and resistance. The inertias of the suspended coil and of the controlled devices make these magnifiers insensitive to high frequencies, and while this has some advantages in discriminating against high frequency disturbances, it also sets a rather definite limit to the speed at which they may be used. In order to utilize them as efficient signal shaping devices the natural frequency must be not far from one and one half times the nominal signaling frequency.[5] On this account and because their sensitivity decreases roughly as the square of the natural frequency to which they are adjusted, the moving coil magnifiers are rarely operated at signaling speeds of more than fifteen cycles per second. As they are easily damaged by relatively small overloads it is not safe to keep them in circuit when the approach of a thunder storm to a cable terminal makes the reception of induced surges in the cable likely. This sometimes results in keeping a cable out of operation for several hours, although the surges would only occasionally cause the loss of a letter if the magnifiers were not subject to damage by overloading.

A vacuum tube amplifier is free from many of the disadvantages of the mechanical amplifiers. It contains no delicate parts which require skilled manipulation, and once adjusted it maintains its adjustment indefinitely. There is no inherent limitation to the speed at which it may be operated; this being determined only by the requirement that the signal be sufficiently stronger than the interference. There is no practical limit to the amount of power which may be controlled and at the same time it is easy to limit this power and insure that momentary overloading shall not damage the amplifier or the associated apparatus. A multi-stage vacuum tube amplifier possesses still another important property in that there is practically no reaction between its various stages at telegraph frequencies. For this reason a number of interstage shaping networks may be used, and it will be found that the adjustment of one network is entirely without influence on the effects of the others.

## History of Development of Vacuum Tube Amplifiers in Bell Telephone Laboratories

The signal shaping amplifier now in use is the outgrowth of studies of the applications of vacuum tubes begun in the laboratories of the

[5] Milnor, *A. I. E. E.*, February 1922.

American Telephone and Telegraph Company and the Western Electric Company in 1912. The vacuum tube amplifier appeared to offer important advantages for use on submarine cables because of its lack of distorting effects which are a function of the frequency of the current amplified, and also because of the ease with which signal distortion correcting circuits could be associated with the vacuum tubes. The initial studies on amplifier circuits suited to currents of the low frequencies involved in submarine cable telegraphy were made by Mr. R. V. L. Hartley and Mr. B. W. Kendall.[6] One of the difficulties which loomed quite large at that time was that most cables were operated duplex and the connection of an amplifier to a duplex circuit would involve the insertion of a transformer which promised to introduce distortion[7]. A suitable distortionless amplifier was first tried and subsequently distortion correcting networks were introduced between its stages. It was found that this permitted the use of more correcting elements than had been feasible in previous practice and thus indicated the possibility of attaining higher speeds than were usual at that time. The development of the shaping circuits employed was at first based on the principle of producing the various derivatives of the arriving current wave and adding them in proper phase relation to the arriving wave. This principle and methods of applying it had been developed mathematically by Mr. J. R. Carson of the American Telephone and Telegraph Company.[8] Mr. R. C. Mathes who conducted the experimental investigation beginning in 1916 simplified his work somewhat by recognizing that this principle was equivalent to a statement that the received signal would be satisfactory if the attenuation and phase distortion of the entire system of cable and amplifier for steady state alternating currents were corrected by the shaping networks over a range of frequencies from nearly zero to approximately the nominal signalling frequency. By the middle of August 1918 the employment of improved shaping methods made speeds of 22 cycles possible in simplex working on an artificial cable having a KR. of 2.7. The then standard cable apparatus would have permitted a speed of not more than 9 cycles, on a cable subject to interference of the magnitude usually encountered.

[6] B. W. Kendall, U. S. Patent No. 1,491,349, April 22, 1924.

[7] Expedients for avoiding distortion of this nature were suggested by Dr. H. W. Nichols of these Laboratories and by Mr. Lloyd Espenschied of the A. T. & T. Co. Their plans contemplated the modulation of an alternating current of relatively high frequency by the incoming signal, the amplification of the modulated current by suitable apparatus and its subsequent demodulation for obtaining the amplified low frequency signal (H. W. Nichols U. S. Patent No. 1,257,381, February 16, 1918; Lloyd Espenschied, U. S. Patent No. 1,428,156, September 5, 1922).

[8] See U. S. Patents No. 1,315,539, September 9, 1919, No. 1,450,969, April 10, 1923, No. 1,516,518, November 25, 1924 and No. 1,532,172, April 7, 1925. See also article by Dr. K. W. Wagner, *Electriche Nachrichten-Technik*, October 1924.

This apparatus [9] was then demonstrated to officials of the Western Union Telegraph Co. and with the cooperation of their engineers tests extending over a period of about a year were carried on at Rockaway Beach on several of the cables entering that station. It was shown in these experiments that while the vacuum tube amplifier together with suitable distortion-correcting networks would permit a considerable increase in the simplex speed (limited only by the interference present in the cable), the duplex speed was limited by the imperfect balance between the cable and the artificial line, and the increased sensitivity and signal shaping ability of the amplifier were of little value under the conditions then obtaining. Serious efforts were made to utilize the current limiting properties of vacuum tubes in conjunction with differentiating and integrating networks in reducing the effect of the unbalance on the signal and some successful results were attained.[10]

By 1920 the research leading to the development of the permalloy loaded cable had progressed to a point where it was evident that a new type of high speed cable amplifier would be required and the investigations were continued with this end in view. After the solution of numerous difficulties an amplifier was produced which was capable of correcting almost any variety of signal distortion which might be caused by a loaded cable. An amplifier of this type was tested on a trial length of 120 miles of loaded cable laid in a loop out of Devonshire Bay, Bermuda, and found to be generally satisfactory. The amplifier was then redesigned in a form suitable for commercial use and two amplifiers were built and installed at Rockaway Beach and Fayal in readiness for the New York-Azores loaded cable. They were put into successful operation and the predicted speed of 1,500 letters per minute was demonstrated within an hour after the cable had been released by the electricians of the ship which laid it.

## Circuit Arrangements of Signal Shaping Vacuum Tube Amplifier

The electrical requirements of a cable signal shaping amplifier suitable for use on high speed loaded cables may be briefly stated as follows. It must take an input signal having components as low as one half millivolt and as high as possibly ten volts in amplitude, and correct the distortion by amplifying the weaker components much more than the stronger, at the same time making any necessary phase

[9] See U. S. Patents to R. C. Mathes No. 1,311,283, July 29, 1919, No. 1,426,755, August 22, 1922, No. 1,493,216, May 6, 1924 and No. 1,586,821, June 1, 1926; also Canadian Patent No. 207,231, January 4, 1921, granted to B. W. Kendall.

[10] D. K. Gannett and M. Kirkwood, U. S. Patent No. 1,483,172.

corrections. It must also be able to operate satisfactorily with signals in which the weaker components may be as strong as 100 millivolts. An output of about fifteen milliamperes at 15 volts should be available and this output must be adjustable by small steps. It must be capable of handling currents containing frequencies between a small fraction of a cycle and about 180 cycles, the particular part of this band of frequencies which is utilized depending on the nature of the cable and the speed at which it is operated.

These requirements are met in the present cable amplifier,[11] by circuits which are shown in the upper half of Figure 1. The amplifier proper consists of four stages of vacuum tubes, the first three being designed for high voltage-amplification and the last for large current output. An additional output stage is provided for the purpose of increasing the flexibility of the amplifier by permitting two separate classes of apparatus to be operated simultaneously. The coupling between stages is a combination of two types, the coupling for the very low frequencies being through a resistance capacity network while that for the higher frequencies is by means of an auto-transformer of special design or by highly damped resistance, inductance and capacity networks. The amplifier is connected to the cable through an input network and a shielded transformer. The input network assists in shaping the signal and prevents the first stage of the amplifier from being overloaded by the strong low frequency components of the signal arriving in the cable. The transformer permits earthing the filaments of the amplifier tubes and their associated batteries and avoids the short circuiting of the long balanced sea earth. The latter is used to reduce the effect of electrical disturbances on that part of the cable which lies in shallow water near the shore.[12] The requirements of this transformer are quite unusual as it must have a satisfactory voltage regulation from .2 to 200 cycles per second.

The ability to operate on voltages which may vary widely from time to time makes it necessary to provide a suitable range of adjustment of amplification. This is accomplished by providing that the secondary windings of the input transformer may be connected in series or in parallel and the plate coupling resistances of the tubes varied by a factor of four to one. A potentiometer placed between the second and third stages of the amplifier allows a variation of twenty to one in the voltage transmitted to the third stage, and with other adjustments as mentioned above, increases the total range

[11] A. M. Curtis, U. S. Patents Nos. 1,586,970 and 1,586,972, June 1, 1926, and 1,624,395 and 1,624,396, April 12, 1927.

[12] J. J. Gilbert, *Bell System Technical Journal*, July 1926; also British Patent No. 218,261, August 31, 1925, and Canadian Patent No. 265,944, Nov. 16, 1926.

of amplification adjustment to about 150 to 1. In addition a set of constant resistance potentiometers in the relay control panel associated with the amplifier allows the current through any of the relays to be varied in small steps without influencing the current in the other relays or changing the impedance of the amplifier output circuit.

The characteristic of the amplifier system may be measured by applying a certain input voltage at varied frequencies, and noting the corresponding output voltage. If the amplifier has been adjusted to give a satisfactory signal when connected to a cable, measurements will show that its amplification increases rapidly to a maximum which occurs at about 1.5 times the signaling frequency, and then falls to practically zero at about twice the signaling frequency. This elimination of the higher frequencies is effected by proper adjustment of the inter-stage shaping networks, and it results in suppressing that portion of the interfering currents received from the cable which lie above the band of frequencies required to form the signal.

The amplifier as described above is perfectly suitable for recorder operation and will permit communication at speeds up to at least ninety cycles per second which in cable code is equivalent to about 2,800 letters per minute, provided that a suitable recorder is employed. It is, however, not entirely suitable for multiplex printing telegraph operation under all conditions without the addition of apparatus to prevent "zero wander."

## System for Correcting "Zero Wander"

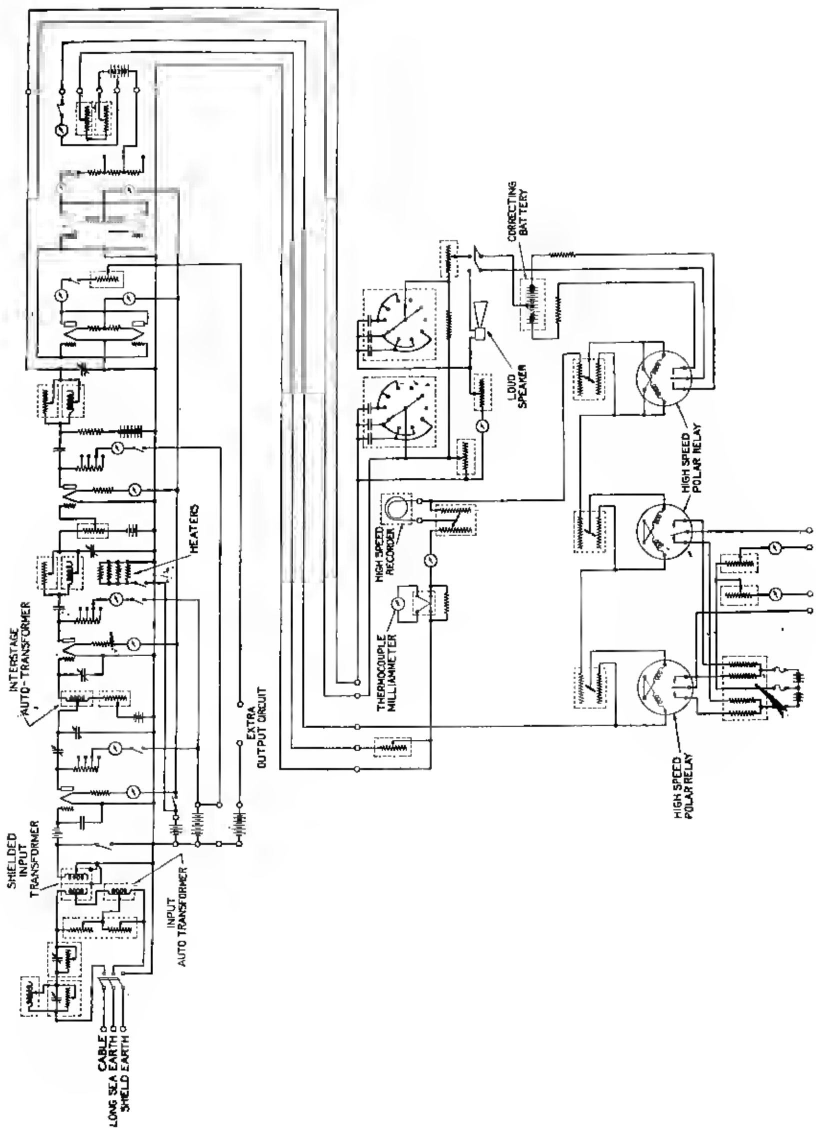
In general, printing telegraph systems have been designed on the assumption that they were to work over land telegraph lines and they contain no provision for avoiding the effects of the "wandering zero" which is caused by the inability of a practical cable transmission system to transmit direct current. This inability to transmit direct currents is due to the fact that there is usually present in a submarine cable an earth current which is many times as strong as the signal, and it is necessary to block out this earth current by series condensers (as is usual in ordinary cable practice) or to keep it out of the amplifier by a transformer. The syphon recorder does not require that the zero of the signal be maintained closely but cable signal relays operate on a fixed value of current of either polarity and are incapable of determining whether or not part of this current is due to a displacement of the zero. It is therefore necessary to reconcile in some way the printing telegraph systems, which under some conditions require the reception of a direct current, with the cable system which cannot transmit a direct current. Several methods of doing this have been

used with the mechanical amplifying systems on low speed cables; they usually supply directly to the relay a "zero correcting" current which depends upon the past history of the signal.[13]

When a vacuum tube amplifier is employed it is more convenient to apply the zero correction to the grid of the last stage vacuum tube as this results in the most economical utilization of the correcting battery and its circuits. The zero correcting apparatus is mounted in a cabinet adjacent to the amplifier and differs considerably in principle from that hitherto used with mechanical amplifiers.

The three element moving armature polarized relay, which had been designed for use in loaded cable operation generally, was changed in some details and adapted for use in the zero corrector. It is capable of operating at a high speed and also discriminates very accurately between currents of slightly differing values. When actuated by the normal signal its armature contacts vibrate between the fixed contacts, not touching either unless the zero of the signal deviates more than about three per cent from its proper position. When this deviation does occur the relay contacts close the circuit for an instant at the peak of a signal wave, and permit the battery to which they are connected to charge a condenser through a comparatively low resistance. The charge on this condenser then passes gradually to a second condenser through a high resistance and at the same time commences to be discharged from the second condenser by a shunt resistance. The voltage on this second condenser is applied to the grid of the last stage of the amplifier in such a sense that it produces a deflection of the amplifier zero in the direction opposite to the deflection which caused the relay contacts to come together. This correcting voltage is applied at a rate which is slow enough to prevent it from distorting the signal and the rate at which it is dissipated by the shunt if no further contacts take place is still slower. It should be noted that these rates of charge and discharge, while adjustable, need not bear any accurate relation to the shape of the signal itself. The correction is usually applied rapidly enough so that the zero is brought back to normal within the duration of about five signal pulses and the proper operation of the circuit prevents the zero from passing beyond limits about five per cent of the signal amplitude either side of the normal position. A somewhat simplified circuit of the relay control unit which includes the zero corrector is shown in the lower part of Fig. 1.

[13] A system in common use is due to S. G. Brown (British Patent No. 6,275, February 20, 1913). Other systems have been invented by D. K. Gannett and M. Kirkwood, U. S. Patent No. 1,548,878, Aug. 11, 1925, and R. C. Mathes, U. S. Patent No. 1,295,553, February 25, 1919.



CABLE
LONG SEA EARTH
SHIELD EARTH
SHIELDED INPUT TRANSFORMER
INPUT AUTO TRANSFORMER
INTERSTAGE AUTO-TRANSFORMER
HEATERS
EXTRA OUTPUT CIRCUIT
THERMOCOUPLE MILLIAMMETER
HIGH SPEED RECORDER
LOUD SPEAKER
CORRECTING BATTERY
HIGH SPEED POLAR RELAY
HIGH SPEED POLAR RELAY


FIG. 1.

MECHANICAL DETAILS OF AMPLIFIER AND RELAY CONTROL DESK

The construction of the amplifier and relay control desk is shown in the accompanying figures. Fig. 2 is a front and Fig. 3 a back view of the amplifier in its cabinet, Fig. 4 is a back view of the panel frame removed from the cabinet and Fig. 5 is a front view of the relay control panel associated with the amplifier. Mechanically the amplifier

FIG. 2.

consists of a frame of brass angles supporting on its front face four large hard rubber panels and sixteen small ones. The four large panels are mounted on the upper part of the frame, and hold the switches and the meters which it has been found desirable to provide in the filament and plate circuit of each vacuum tube. The adjustable elements of the amplifier interstage shaping networks are contained in the sixteen smaller panels mounted in the lower part of the framework. Each of these panels is a complete unit, comprising either a variable condenser, a variable resistance, or a switch for the adjustment of an

inductance. As these panels are all of the same size, it is possible if necessary to change radically the arrangement of the interstage networks, or substitute entirely different ones without any difficult mechanical work on the amplifier. Each of the condensers and resistances is contained in an earthed metal box, into which it is sealed by a wax insulating compound. The frame in which the panels are

Fig. 3.

mounted is earthed and metallic fins are provided between the various panels in such a manner that any current which leaks through a film of moisture which might be deposited on the surface of the panels must pass to earth. The plan of mounting each individual piece of apparatus in a metal box, and sealing it in with insulating compound, has been adhered to throughout, the tubes, meters and switches of course being excepted. This is principally for protection from the serious humidity frequently found in cable stations. Additional protection is provided by electric heaters drawing current from the battery which operates the filaments of the vacuum tubes. Frame-

work shelves provide space for mounting the tubes and heavy apparatus such as coils and coupling condensers. The tube of the first stage is held in a spring suspended socket, damped by an oil dashpot.[14] The socket of the second stage tube is sufficiently protected from vibration by a sponge rubber mounting, while the sockets of the third and fourth stages need no special protection. Dry cell grid batteries are mounted on the lower shelf of the framework. The numerous external connections are brought to the terminal strip which may be seen along the lower part of the back of the framework. The panel assembly is mounted in the upper part of a mahogany case, lined with copper. The lower part of the case contains the shaping

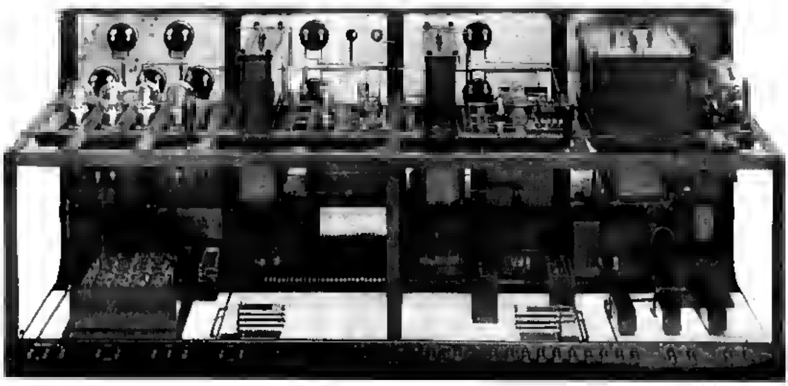


FIG. 4.

networks which are connected between the cable and the amplifier All adjustments are made either from the front of the panels or on apparatus contained in the lower part of the cabinet, and as all the elements of the amplifier are inherently stable, when the adjustments for shaping the signal at any given speed have once been determined they may be quickly duplicated at any time.

The relay control desk combines the apparatus for correcting the signal zero wander with means for adjusting the current through the relays used in the multiplex printing telegraph system and includes several switches used in the control of the latter apparatus.

In designing the amplifier the necessity of maintaining continuous operation and easily and quickly remedying any minor troubles was considered of the utmost importance, and this led to its being made large enough so that work may be done inside of it without having to remove

[14] W. A. Knoop, Patent U. S. No. 1,523,430, January 20, 1925.

it from the circuit and take it apart. All of the circuit elements may be reached from the back of the cabinet without disturbing anything else, and on several occasions this arrangement has proved of great value.

### Power Supply for Amplifier

Three sets of storage batteries are required for an amplifier. The filaments are heated by a 6 V. 500 AH storage battery. The plate voltage for the first three stages is supplied by a 250 volt 1 AH storage

Fig. 5.

battery while the plate voltage for the last stage is supplied by a 275 V. 4 AH storage battery. These batteries are in the general battery room of each cable station and are handled by ordinary methods, the only special precautions necessary being the shielding

of the leads from battery to amplifier and the avoiding of loose switch contacts.

## RESULTS OBTAINED IN SERVICE

The first two amplifiers built were put in operation on the New York-Azores cable in September 1924, and after a few weeks' testing a speed of 65 cycles per second or about 2,080 letters per minute in cable code was demonstrated. In the fall of 1926 three additional permalloy loaded cables were completed and equipped with vacuum tube amplifiers. They are laid between New York and Bay Roberts, Newfoundland, between Bay Roberts and Penzance, England, and between Fayal, Azores, and Emden, Germany. A speed of ninety cycles has been demonstrated on the New York-Bay Roberts cable, and the longer section from Bay Roberts to Penzance has worked at eighty cycles. The adjustment of amplification and the flexibility of the shaping networks is such that it has proved possible to remove an amplifier adjusted for operation at about 40 cycles from the long New York-Azores cable and readjust it for use on the short New York-Bay Roberts cable at 20 cycles in about fifteen minutes.

During the two and one half years of operation of amplifiers on the New York-Azores cable the maintenance required has been almost negligible and the rare cases of trouble have usually been found in the external connections. The longest delay to traffic caused by the amplifiers during this period was about two hours, and was due to the disarrangement of some temporary wiring. The reliability of the amplifiers is well attested by the fact that during the first two years there was only one available at each station, and there was no difficulty in keeping cable and amplifiers in continuous operation.

In connection with maintenance the vacuum tube amplifiers have a great advantage in that they do not require any delicate mechanical adjustments, while the electricians responsible for the operation of mechanical amplifiers must frequently spend hours at tasks requiring the skill and patience of a watchmaker.

It has been found possible to handle messages during thunderstorms which prevented operation of the non-loaded cables and their mechanical amplifiers for several hours. As an experiment the loaded cable and amplifier were worked continuously through an unusually severe thunderstorm during which stop watch observations of the intervals between lightning flashes and thunder claps showed that lightning had struck within a thousand feet of the cable terminal on three occasions. Although the induced surges were frequently several times as strong as the signals, the automatically limited output of the

amplifier protected the recorders from damage, and the effect of each lightning discharge was limited to the possible mutilation of one or two letters.

The protection of these amplifiers from mechanical vibration has proved entirely satisfactory. During alterations to the Western Union Cable station building at Rockaway Beach a brick wall six feet from the amplifier was broken down with sledge hammers without interfering with the normal handling of messages.

## Other Applications of Vacuum Tube Amplifiers in Cable Telegraphy

While as yet vacuum tube amplifiers have been utilized principally on high speed loaded cables they are not necessarily restricted to such use. It was mentioned in an early part of this paper that, since the non-loaded cables are ordinarily operated duplex at a speed which is set, not by the sensitivity of the receiver, but by the strength of the interference due to imperfect balance between cables and artificial line, no increase in speed might be expected to result from the substitution of vacuum tube amplifiers for the mechanical amplifiers now used. Nevertheless the superior ruggedness of the vacuum tube amplifier, combined with its ability to operate safely through thunderstorms which would ruin the mechanical amplifiers, might reduce appreciably the amount of lost time, particularly during the summer months, and thus improve the traffic capacity of these cables.

In addition to the use of vacuum tube amplifiers for operating terminal apparatus they have another important field as repeaters intermediate between two short sections of a long cable. As the speed at which any cable can be operated is roughly inversely proportional to the square of its length, it is customary to lay cables connecting distant centers of population in two or more sections, interrupted at some conveniently located but often inconveniently isolated island. This involves repeating the signals received from one section of the cable into the next section and for years this was done manually, that is, an operator received and translated the signals and passed them on to another operator for transmission on the other section. Within recent years through relay operation by means of repeaters has become general. At the intermediate station a device receives the signal from an amplifier and retransmits it to the next section usually correcting it completely to its original form. These repeaters, while very successful, are still quite complicated mechanically, and require skillful maintenance, particularly as they utilize delicate mechanical amplifiers and moving coil relays. It is possible to replace

them by vacuum tube amplifiers having no moving parts, and thus requiring a minimum of maintenance. The vacuum tube amplifier is capable of reshaping the signal almost as completely as is done by the mechanical repeaters, and, in case of a cable worked simplex, the direction in which the amplifier at the intermediate station repeats the signal may be automatically controlled from either the sending or the receiving station.